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RESULTS FROM THE DIRAC EXPERIMENT AT CERN

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ABSTRACT

The goal of the DIRAC experiment is to measure the lifetime of the $\pi^+\pi^-$ atom and thus to determine the $\pi\pi$ s-wave scattering lengths $|a_2 - a_0|$. We describe the experimental methods and present first results from a subsample of data taken so far.

1 Introduction

The lifetime of a $\pi^+\pi^-$ atom ($A_{2\pi}$) is due to the reaction $\pi^+\pi^- \rightarrow \pi^0\pi^0$, whose amplitude is proportional to the difference of the s-wave $\pi\pi$ scattering lengths

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for isospins 0 and 2. Measuring the lifetime thus provides a measure of $|a_0 - a_2|^2$. The lifetime is about 3 femtoseconds and can be predicted theoretically [1, 2] with high precision. Measuring the lifetime thus provides a test of theory.

The method of measuring the lifetime has been developed by Nemenov [3]. Atoms produced in a high energy proton nucleus collision propagate until they annihilate. In a target of finite thickness the relativistic atom ($\gamma \approx 17$) collides with target atoms and becomes excited and/or broken-up. Cross sections and transport dynamics can be calculated accurately and a relation between break-up probability and lifetime can be established as a function of target material, target thickness and momentum of the $A_{2\pi}$ [4].

Pion pairs from break-up can be detected through their specific feature of very low relative momentum Q. In Figure 1 the distributions are shown for Q and its longitudinal component Q_L, at break-up and at the exit of the target.

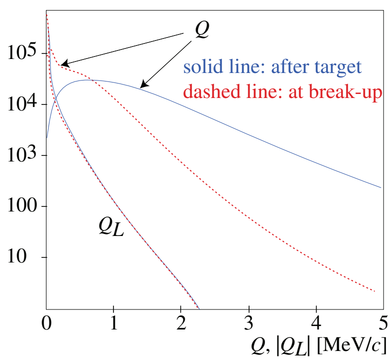

Figure 1: *Q and Q_L distributions of π^+ - π^- pairs from atomic break-up, at break-up (dashed) and at target exit (solid line). Remark the broadening of the Q distribution due to multiple scattering.*

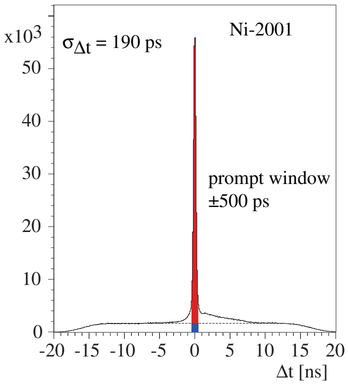

Figure 2: Time difference between positive and negative vertical hodoscope slabs associated with the selected tracks. The asymmetry for positive differences is due to protons.

Experimentally the measurement of a signal of $\pi^+\pi^-$ pairs from atom break-up n_A leads to the break-up probability $P_{br} = n_A/N_A$ where the number of produced atoms N_A has to be determined separately. DIRAC uses the background as a normalization for N_A, but has also introduced a method of lifetime determination free of normalization by using two targets.

The DIRAC experiment was proposed in 1995 [5] and has started data production in 1999. Here we report on the results from data taken on Ni targets in the years 2001 and 2002.

2 The Experiment

The DIRAC experiment uses a double arm spectrometer designed for detecting track pairs from pions of opposite charge with low relative momentum Q. Figure 3 shows the set-up of DIRAC. The resolutions are: $\sigma_p/p = 0.3\%$ and $\sigma_{Q_L} = \sigma_{Q_x} = \sigma_{Q_y} = 0.5$ MeV/c. Details may be found in [6, 7, 8, 9, 10].

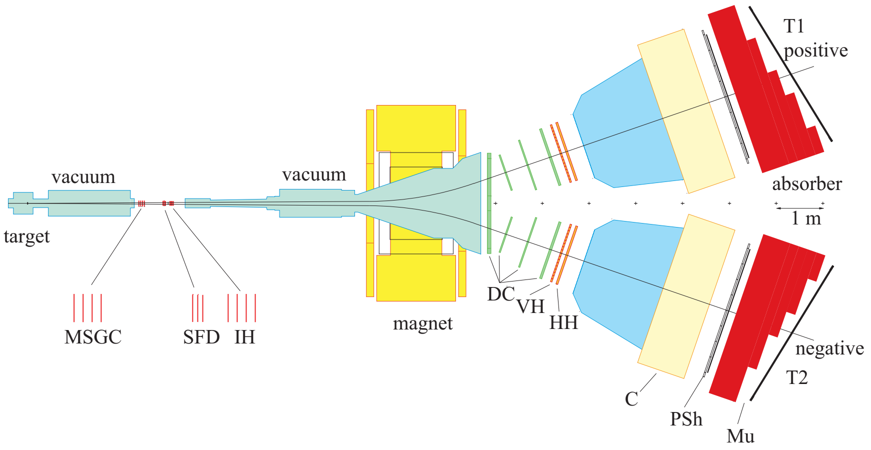

Figure 3: *Schematic top view of the DIRAC spectrometer. Upstream of the magnet: target, microstrip gas chambers (MSGC), scintillating fiber detectors (SFD), ionization hodoscopes (IH) and iron shielding. Downstream of the magnet: drift chambers (DC), vertical and horizontal scintillation hodoscopes (VH, HH), gas Cherenkov counter (Ch), preshower detectors (PSh) and, behind the iron absorber, muon detectors (Mu).*

3 Event selection, reconstruction.

We have analysed data taken in 2001 on Ni targets of 94 μm and 98μm thickness. Two event classes are used: "prompt" events, defined by a time difference (corrected for the flight path assuming pions) in the VH's between the positive and the negative arm, $|\Delta t| \leq 0.5$ ns, and "accidental" events, defined by $-15 \leq \Delta t \leq -5ns$ and $7 \leq \Delta t \leq 15ns$ (cf. Fig. 2). $e^{\pm}$ and $\mu^{\pm}$ are rejected (Cherenkovs, Preshower and the Muon counters). Cuts are applied on $\sqrt{Q_x^2 + Q_y^2} = Q_T \leq 4\,\mathrm{MeV}/c$ and $|Q_L| < 22\,\mathrm{MeV}/c$. Reconstruction uses standard methods including Kalman filtering.

4 Background

Prompt pion pair background is produced by pions from hadronization or decay of short lived secondaries (e.g. ρ mesons), and decay of long lived particles (e.g. η mesons). Pions from the former background undergo final state Coulomb interaction, which results in an enhancement at low Q (Coulomb correlated (CC) background), while the second type of background is not affected (nC-background). Accidental background originates from two different proton interactions and is also present in the prompt time window (cf. Fig. 2).

5 Simulations.

The backgrounds and the break-up signal were simulated using appropriate generators (phase space for nC and accidental background, additional Coulomb enhancement for CC background [11], and atomic break-up). The spectrometer was simulated with GEANT4. Detectors, triggers and digitalization were fully simulated. Thus Monte Carlo data could be treated as real data.

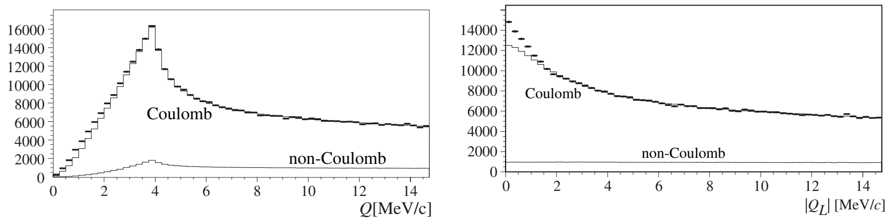

Figure 4: Measured prompt distributions in Q qnd Q_L. The fitted Monte Carlo backgrounds are also displayed [12].

6 Signal extraction.

The signal (number of detected broken-up atoms n_A^{exp}) was obtained by approximating the prompt experimental Q and Q_L distributions with the Monte Carlo background distributions and with the (fixed) accidental distribution obtained from an extrapolation from the accidental window into the prompt window (cf. Fig. 2). The properly normalized backgrounds were fitted outside the signal region (see Fig. 4) and then subtracted from the experimental distributions (see Fig. 5).

7 Normalization and Break-up probability.

The break-up probability is $P_{br} = n_A/N_A$ with n_A the number of broken-up atoms and N_A the number of produced atoms. N_A may be obtained from the CC background since atom formation and Coulomb correlation are the same physics processes. Thus, theory provides $N_A = 0.615 N_{CC}^{norm}$ with $N_{CC}^{norm} = \int_{0\ MeV/c}^{2\ MeV/c} N_{CC}(Q)dQ$. Monte Carlo provides the fraction κ of N_{CC}^{norm} of the total reconstructed CC-background below a cut limit to be chosen, $N_{CC}^{Q\leq Q_{cut}} = \int_{0\ MeV/c}^{Q\leq Q_{cut}} N_{CC}^{exp}(Q)dQ$. Then $N_A = 0.615 \times \kappa \times N_{CC}^{Q\leq Q_{cut}}$. The fraction ϵ of detected pairs from break-up whithin the same cut limits of total broken-up atoms is also obtained by Monte Carlo. The break-up probability thus becomes $P_{br} = n_A^{exp}/(0.615\ \kappa\ \epsilon\ N_{CC}^{Q\leq Q_{cut}})$. With the number of events obtained from the fit [12], $n_A^{exp} = 6560 \pm 295$, $N_{CC}^{Q\leq 4MeV/c} = 106114 \pm 1010$, and $0.615\ \kappa\ \epsilon = 0.1383$ we obtain $P_{br} = 0.447 \pm 0.023_{stat}$.

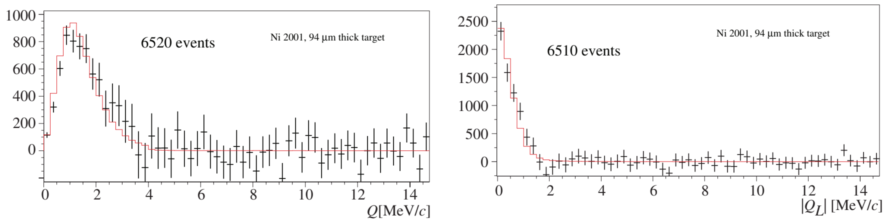

Figure 5: Measured prompt distributions in Q qnd Q_L after background subtraction. The Monte Carlo simulated atomic pair shapes are also displayed. [12]

8 Systematic errors.

We have investigated a large number of systematic errors, the most important ones being linked to differences in results obtained from Q and Q_L separately, to the CC background determination, to the line shape and to multiple scattering. We found a slight dependence of the CC background on the upper end of the fit range. We also found a dependence of the break-up probability on the line shape, but with diminishing importance when taking the whole signal ($Q_{cut} = 4MeV/c$). Variations in multiple scattering ($\pm$ 5% in scattering angle) yield small deviations. The total systematic error [12] of the break-up probability is estimated to be $\pm$ 0.009.

9 Lifetime.

With $P_{br} = 0.447 \pm 0.023_{stat} \pm 0.009_{syst} = 0.447 \pm 0.025_{tot}$ we deduce a lifetime of $\tau = 2.85\ ^{+0.48}_{-0.41}$ [fs].

10 Conclusions.

The analysis presented here is obtained with only ≈ 30 % of all data collected so far by DIRAC. All the above results can be found in [12] and are preliminary[1]. However, the systematic errors seem to be under control and are smaller than the statistical ones. This is also true if all the data of DIRAC will be used. In this case the total error on the lifetime will be around 10%.

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[1] In the sense that independent cross checks have still to be done.

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